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[Following is the translation of an article entitled "Svoystva i osobennosti alyuminiyevykh vzrychatykh veshchestv" (English version above), by Candidate of the Physicomathematical Sciences S. B. Ratner in Gornyy Zhurnal (Mining Journal), Vol. 121, No. 5, Moscow, 1947, pp 21-25.]

As regards the amount of oxidation energy per unit of weight, aluminum occupies one of the first positions among the elements. The combustion of aluminum produces Al_2O_3. The energy of formation for this oxide (from metallic aluminum and molecular oxygen in the gaseous state) is equal to 390 kilo-calories/mole, or 7.2 kilo-calories per gram of aluminum. Until very recently it was thought that in an explosion, aluminum oxide was produced in solid form. Not long ago, however, the possibility of its evaporation has been indicated (1). This requires the expenditure of about 120 kilo-calories/mole, which decreases by one-third the energy of combustion of aluminum. The boiling point of Al_2O_3 under the conditions of a detonation wave reaches roughly 5000°. Consequently, an appreciable portion of the aluminum oxide can evaporate in an explosion, and this will alter considerably the explosive properties of a mixture.

The most important class of aluminum explosives is the ammonal group. Let us examine the simplest case, in which the mixture consists of 81.5% ammonium nitrate and 18.5% aluminum (in practice one should employ 80/20 ammonal, since crushed aluminum contains as much as 10% inactive impurities, mainly aluminum oxide). Such a proportion of ingredients insures a null oxygen balance according to the reaction:

$$2Al + 3NH_4NO_3 \quad Al_2O_3 + 6H_2O + 3N_2 + Q$$

In the case where solid aluminum oxide is formed, the explosive energy (Q) is equal to 1680 kilo-calories/kilogram; with gaseous aluminum oxide formed, it is 1270 kilo-calories/kilogram. The same difference (400 kilo-calories/kilogram of mixture) results with all of the other mixtures containing 18% aluminum. In introducing aluminum into a mixture not having a positive oxygen balance, the loss of some energy in the quantity of original mixture removed must be taken into account. Thus, for example, high explosives, to which aluminum is often added, have an explosive energy of about 1000 kilo-calories/kilogram. The introduction of 1 gram of aluminum results in the additional loss of 1 kilo-calorie.

If the introduction of aluminum in general affects favorably the energy of an explosion, the same may not be said of its influence on the second physico-chemical factor which determines explosive properties, i.e., on the volume of the products of an explosion. In particular, 80/20 ammonal gives off gases at 700 liters/kilogram approximately, while the ordinary explosives without aluminum give off up to 1000 liters/kilogram. This fact must be emphasized in connection with the erroneous position taken by Muraour (2). Even assuming that aluminum oxide is formed in the solid state, he asserts, the addition of aluminum does not reduce the volume of gas for explosives having a negative oxygen balance.

Fugacity and Brisance

The effects of the addition of aluminum on the basic explosive characteristics of ammonium nitrate mixtures are given in the data [see note] of Table I. (Note: These experimental data, as well as those which follow without the mention of their source, are taken from the work of S. B. Ratner, T. I. Savel'yeva, and Yu. B. Khariton, Institute of Physical Chemistry of the Academy of Sciences of the USSR)

TABLE I. Brisance and fugacity of some ammonium nitrate mixtures

Ingredients, %				Brisance by Hess method in mm.			Oxygen Balance
ammonium nitrate	aluminum	TNT	naphthalene	density 1 gm/cm^3; detonator -capsule	density 1.3 gm/cm^3; detonator 18gm. tetry 1	Fugacity by the Trauzl method, in cm^3	
80	20	—	—	15.5	22	520	Null
80	—	20	—	15	22	400	"
93.8	—	—	6.2	14	11	360	"
80	10	10	—	15	22	450	"
86.9	10	—	3.1	15	20	450	"
83.4	10	5	1.6	15	—	440	"
90	10	—	—	15	21	420	Positive
86	8	6	—	15	21	410	"

Mixtures containing even a part of the aluminum necessary to bind the additional oxygen in the ammonium nitrate yield a greater fugacity than the ordinary compounds without aluminum. This quantitative index is especially important (it is over 500 cm^3) for the double mixture of 80/20 ammonal, the null oxygen balance of which is wholly assured by its aluminum content.

Such figures for the fugacity are attainable with a few of the powerful compounds — for example, nitroglycerine and hexogen, whose decomposition energy is close to 1500 kilo-calories/kilogram. If one takes into consideration that the maximum energy of 80/20 ammonal is greater than 1500 kilo-calories/kilogram, then the fugacity effect of this mixture is not so surprising. Its brisance effect, however, which differs little from that of substance having half again as much energy, seems unexpected from the standpoint of formal energy considerations.

The brisance and fugacity of explosives cannot both be determined by the temperature of the blast. The fugacity effect is a consequence of the prolonged action in an explosion (for example, the formation of a funnel in the test block, as in Trauzl's method); in this, the energy of the blast is utilized to the fullest possible extent. The brisance effect, on the other hand, is determined over a very small period of time in the explosive action (as in the fragmentation and compression within the crusher gage, i.e., the test of Hess or Kast, and others); this is mainly the result of the application of maximum pressure. Thus, if additional energy is released in the other stages of an explosion, it may appreciably affect the fugacity effect, without having any important influence on the brisance. Consequently, the brisance of an explosive does not correspond to its fugacity.

For the ammonals, such a divergence had already been indicated in the well-known work of Kast (3), who writes: "The brisance of ammonal cannot be compared to that of such powerful aromatic nitro compounds as picric acid and trinitrotoluene. Its fugacity effect, however, in a block of moderate hardness and with tight packing is considerably greater than for the above mentioned compounds." (page 344)

It can be seen from Table I that the disparity between fugacity and brisance has been observed for 80/20 ammonal. To explain this, it is necessary to find the link in the process at which there is a gradual release of heat. In going about this, two possibilities must be indicated: 1) The evaporation and consequent condensation of the aluminum oxide; 2) The gradual entry into the reaction of metallic aluminum; in addition to this, the decreased amounts of gases in the aluminum explosives could have some importance.

Ratner and Khariton (1) hold the view that if sufficiently granulated, aluminum oxidizes practically until the expansion of the explosive products. However, the speed of detonation of a mixture is unaffected by that part of the energy which is contained in the vaporous aluminum oxide in the form of heat of sublimation. But later on, during the process of expansion, the temperature drops and the aluminum oxide solidifies. This is accompanied by the release of the heat of condensation and increases the fugacity effect, since it assists in the maintenance of the temperature and pressure of the other gaseous components (H_2O, N_2 and others). Therefore the addition of aluminum, which leads to a significant increase in the fugacity effect, can result only in a less noticeable (frequently insignificant) increase in the speed of detonation, and hence in the brisance.

The second possibility is quite conceivable, since not all of the aluminum particles added to an explosive are equally fine. In this context, we should mention the extreme view taken by Kast (3), according to which the oxidation of all the aluminum is a secondary process occurring during the expansion of the products of the explosion. Muraour also holds that in explosives of the ammonal type, the aluminum has its effect only after the passing of the detonation wave, and that the heat released in the combustion of the aluminum merely retards the cooling of the gases. But if this were indeed the case as Kast and Muraour describe it, then the energy of oxidation of the aluminum would not affect the speed of detonation, which would be the same for the double mixture of aluminum with ammonium nitrate as for pure ammonium nitrate. Experiment shows the error of Kast's hypothesis: the speed of detonation for 80/20 Ammonal at a density of 1 gram/cm^3 is equal to 4 kilometers/sec, but for ammonium nitrate (under the same conditions) it does not exceed 2.5 kilometers/sec. The same relationship likewise holds for the brisance.

Indubitably, the large particles of aluminum react longer than the small. However, this is not a specific characteristic of aluminum or the other metallic additives. Such a "serial" effect must take place in the detonation of all explosive mixtures containing non-explosive ingredients (for example, peat). This is indeed the reason for the generally known fact that the brisance of such mixtures is, as a rule, comparatively smaller than their fugacity, if they are compared with homogeneous explosives with equal energy and volume of gases discharged.

Finally, the third reason for the observed disparity lies in the effect observed by A. F. Belyayev (4), of the degree of expansion of the products of an explosion on the work it performs. According to Belyayev, the fugacity effect corresponds to the large degree of expansion, which results in the optimum employment of energy; the brisance effect corresponds to a small degree of expansion. Insofar as the products of an explosion serve as the carriers of energy, a small number of them results in a small brisance effect, even in the presence of a rather large energy potential in the explosive. Since aluminum mixtures are charact-rized by a rather small volume of gaseous products, they have a particularly large disparity between the brisance and fugacity effects.

In this way, all three factors are directed toward the same result. The two latter reasons must be operative for any of the aluminum explosives; an even change in the proportion of the ingredients should evoke an even change in the correlation between the brisance and fugacity.

On the other hand, the reason indicated by Ratner and Khariton is somewhat original. It occurs only at high temperatures, since otherwise aluminum oxide will begin to appear in the solid form even before the expansion of the products of the explosion. In ammonals of low caloric potential, the heat of condensation for the aluminum oxide must influence both the brisance and fugacity effects. The correlation between them will turn out to be completely different than in the case of the powerful ammonals, for which the aluminum oxide quickly evaporates in the detonation wave, to condense only later in the expanding products of the explosion.

This is the main reason producing the disparity between the brisance and fugacity effects of powerful aluminum explosives, this fact being proven by the data presented in Table 2. It shows, together with the facts presented above, that increases in brisance decline sharply for the ammonals with the addition of aluminum oxide above 10%.

Cases in Which It Is Useful to Employ an Admixture of Aluminum

The employment of an admixture of aluminum to any explosives is most effective when their fugacity effect is being utilized; and in the case of the low-energy explosives, when they are utilized for their brisance effect.

In actuality, the temperatures reached in the explosion of low-caloric aluminum explosives are insufficient to vaporize the aluminum oxide. The latter forms in the solid state, releasing the energy of condensation at the wave-front. There must be no disparity between the brisance and fugacity for these mixtures.

But just where is the borderline between these two groups of explosives? As long as the exact calculation of either the temperature of the aluminum oxide in the detonation, or the temperature of the explosion is impossible, this question must be answered empirically. Let us look at some examples.

In Table 2 are given the experimental figures for the brisance and fugacity of the simplest ammonals and amatols containing varying quantities of aluminum or, correspondingly, trotyl. It is interesting to compare these data with the corresponding figures for the explosive energy, given in the same table.

TABLE 2. Comparison of fugacity, brisance and energy of the simplest ammonals and amatols

Ingredients in Mixture	Fugacity by the Trauzl method, in cm^3		Brisance by the Hess method, in mm.				Energy of explosion, in kilo-calories/gm.		
			Weight-50gm.		Weight-200 gm.		(See Note 1) Ammonal		
	Ammonal	Amatol	Ammonal	Amatol	Ammonal	Amatol	Solid aluminum oxide	Gaseous aluminum oxide (See Note 2)	Amatol
80/20	520	400	15.5	15.1	21.8	20.3	1.6	1.2	1.0
90/10	420	315	15.1	11.6	20.4	15.0	1.0	(0.8)	0.7
95/5	320	270	11.0	8.7	14.8	11.6	0.7	(0.6)	0.5

Note 1: Figures for the energy of the ammonals are rounded off to the lower decimal digits, since aluminum contains inactive impurities.

Note 2: The number in parentheses are not achieved because of the high explosive temperatures of the corresponding ammonals, which do not insure the evaporation of the aluminum oxide formed in the wave.

The brisance and fugacity are correspondingly close to one another for the equienergetic mixtures in those cases where solid aluminum oxide is produced. Occupying a special place is 80/20 ammonal since the value for its brisance exceeds by a small amount that of 90/10 ammonal and 80/20 amatol. It is obvious that the explosion of 80/20 ammonal is accompanied by high temperatures, with the aluminum oxide being produced in the gaseous state. The corresponding values for the energy appear in the last column of Table 2. The figures in parentheses (for mixtures with a low aluminum content) are not achieved because of the low explosive temperatures of these ammonals, which do not insure the evaporation of the aluminum oxide.

It follows from the data of Table 2 that the practical limit for the brisance effect is reached when the aluminum content in the ammonal is about 10%.

It can be concluded in general, that the addition of aluminum does not increase the brisance of those mixtures whose original explosive energy exceeds 1000 kilo-calories/kilogram. It seems to be the case that a mixture of such an energy produces a temperature which almost assures the possibility of significant evaporation of the aluminum oxide, as, for example, in the explosion of 90/10 ammonal. The introduction of any combustible material (among them aluminum) into an equienergetic mixture produces a higher temperature in the detonation wave, at which the process of evaporation increases. This increase is larger, the greater the admixture (within certain limits, until the oxygen needed to oxidize the aluminum is used up). This is the reason why the hidden heat of condensation of the aluminum oxide, whose release constitutes the basic advantage of aluminum mixtures, cannot be employed to increase the brisance of powerful explosives.

Let us examine in this light the divergence between the correlation of fugacities in Trauzl's bomb, and their effectiveness in the bore-hole, which are observed for the ammonals [see note] of Bikhel' 72/23.5/4.5 (brown coal) in comparison with the corresponding Dynammon. According to Venen, Byurlo, and Lekorshe (5), the fugacity of this mixture in Trauzl's bomb is 60% greater than that of coal Dynammon. The authors make this comment: "It turned out in practice, however, that the addition of aluminum produces only a small increase in useful work" (page 436); they also give an incorrect explanation for this discrepancy. There is nothing puzzling about the latter effect, since the process of crushing within the bore-hole must be connected mainly with the brisance and not the fugacity. Furthermore, we have in mind the action of explosives in a hard medium. As far as extraction work is concerned, it is tied up mainly with the fugacity. Our considerations are in agreement with the words of Kast cited above, which speak of "a fugacity effect in a block of moderate hardness with tight packing." (Note: Henceforth we shall designate the percentage composition of the ammonals by giving first the percentage of ammonium nitrate, secondly the percentage of aluminum, and finally that of an additional component. The name of the latter is given in parentheses, if it is unclear from the text.)

It is perfectly comprehensible that the fugacity of Bikhel's ammonal is much greater than for the corresponding Dynammon; but its brisance, which produces the shattering effect, cannot show a similar increase, since the aluminum oxide will certainly evaporate in the wave front in the explosion of a powerful ammonal.

Furthermore, the brisance effect of an explosive can actually decrease with the further addition of aluminum, although the fugacity effect will grow. Examples of this can be found in the recent work of Stettbacher (6), who asserts that the addition of up to 32% aluminum to a certain explosive increased the energy almost 100% but diminished the brisance.

A Survey of Mixtures Employed

The literature on the subject has very little data on the composition of aluminum mixtures employed within recent years. Of the more recent works, in addition to the above-mentioned article by Stettbacher (6), we must refer to that of Muracur (2), who writes of the use made by the Germans in World War II in torpedoes, mines, and underwater grenades of a mixture of hexanitrotoluene with 15% aluminum added, which increased the energy from 1000 to 14000 kilo-calories/kilogram. The so-called "German mixture" may also be mentioned; it contains 89% ammonium nitrate, 2% aluminum, 5% naphthalene and 4% peat or wood meal, and has come into use within the last few years.

In the literature in Kast (3), for example we find numerous recipes employed before, during, and after World War I in civilian, as well as in military industry. No general description of these mixtures may be given, since the proportional content of their ingredients covers a wide range. For example, in a single country (Australia), in explosives used in just one type of work (in mines containing no fire-damp), the three components of the ammonal varied over the following ranges: 80-90% for the ammonium nitrate, 4-18% for the aluminum, and 2-6% for the coal. There was a trend in the world mining industry, due to the high cost of aluminum, to employ mixtures with small quantities of this element (containing about 5% aluminum, and up to 10% of a combustible substance or nitro compound). There were mixtures employed, however, representing the other extreme, with an aluminum content of up to 25% (with the quantity of coal reduced up to 2%). Such a substance is the above-mentioned 72/23.5/4.5 mixture of Bikhel; which has become generally accepted because of its increased fugacity. The mining industry has also frequently employed mixtures with medium quantities of aluminum, such as the English ammonals of Fyurer [Fuehrer] having the composition 68/15/17 (trinitrotoluene).

The last two categories of recipes (rich in aluminum) were most widely used in the military industries.

Such ammonals are characterized by a distinctly negative oxygen balance. The aluminum in them oxidizes mainly at the expense of depriving the other ingredients of oxygen, resulting in the loss of their heat of oxidation.

Of a totally different character was the alumatol concocted in England, which contained only 3% aluminum (and 17% trinitrotoluene), and had a null oxygen balance. Close to this mixture are the ammonals (Table 3) established in GOST Gosudarstvennyy Obshchesoyuznyy Standart -- All-Union Government Standard of the USSR No. 4117 for use in civilian industry.

TABLE 3. Composition of ammonals established by GOST No. 4117

Ingredients	% Content					
	1	2	3	4	5	6
Ammonium nitrate	82	82	86	86	81	81
Aluminum	6	6	5	5	6	6
Trinitrotoluene	12	—	9	—	10	—
Xylyl	—	12	—	9	—	10
Wood meal	—	—	—	—	1	1
Rosin	—	—	—	—	2	2

The first two mixtures have an almost null oxygen balance; 3 and 4 have a positive oxygen balance; 5 and 6 have a negative oxygen balance.

Ease of Detonation. The Influence of Aluminum Dispersion

The evaluation of the possible effectiveness of mixtures depends not only on the energy and volume of the released products of the explosion, i.e., on the chemical composition of the mixture, but also on the physical structure of the charge (diameter, tightness of packing, fitness of granulation). The latter factors strongly affect the ease of detonation, i.e., on the explosive capability and stability.

On the question of the influence of aluminum on the ease of detonation, the opinion prevails which had already been stated by Sukharevsky (7): "Its addition heightens the detonation capability" (page 198). In addition to this, some authors have based practical conclusions on this position. Thus, for example, according to Venen, Byurlo, and Lekorshe (5), "the ease of detonation increases if aluminum is present -- an interesting property from the standpoint of possibly improving explosives" (page 436). The authors base this conclusion on the results of the work carried out by the French Commission on Explosives (in 1903), but they do not cite the relevant facts.

Nevertheless, the experimental facts (Table 4) definitely show that the presence of aluminum does not in itself improve the ease and stability of detonation for the ammonium nitrate mixtures; with comparable dispersion, trinitrotoluene is more effective than aluminum.

TABLE 4. The brisance of ammonals of various densities

Mixture Number	Ingredients, %				Weight of charge (in gm)	Brisance (in mm.) at the given densities, (in gm/cm^3)		
	ammonium nitrate	aluminum powder	very fine aluminum powder	trinitrotoluene powder		1,0	1,3	1,5
1	80	20	—	—	50	16	15	15
					150	5	3	2
2	80	10	—	10	50	—	22	23
					150	—	21	21
3	80	10	10	—	50	19	22	20
					150	21	21	13

The stability of detonation was determined by comparing the compression produced within the lead crusher gage by a 50 gram charge (the standard test of Hess) and that produced by a 150 gram charge of the same diameter (40 mm). The necessity of such a comparison arises from the fact that a detonation, having once started, can proceed a short distance and then become extinguished. If the brisance of the longer charge increases, then the detonation is proceeding evenly, if it decreases, the detonation is not proceeding persistently. Experiments have shown that for ammonium nitrate explosives, the lengths of the charges corresponding to the above-mentioned weights (with the standard diameter of 40 mm in Hess's test) give the correct results. In order to reliably initiate the detonation, it was started in all cases by a capsule containing a supplementary detonator (8 grams of pressed trinitrotoluene).

It can be seen from Table 4 that when aluminum and trinitrotoluene have the same dispersion, the brisance of the ammonal not containing trinitrotoluene (No 1) is worse than that of the mixture containing the same quantity of trinitrotoluene in place of the aluminum (No 2). The brisance properties of ammonals not containing trinitrotoluene increase sharply when the aluminum is more finely crushed than the trinitrotoluene.

Thus the question of the ease of detonation of explosives cannot be divorced from the question of the fineness of the ingredients in the explosive mixture, since their dispersion determines the reaction time. Increasing the dispersion of aluminum produces a more stable detonation. For example (see Table 4), if the detonation does not proceed persistently (mixture No 1), a uniform detonation may be brought about under the same conditions (diameter 40 mm; density 1.0 and 1.3 gm/cm^3), by replacing a part of the aluminum powder with a very finely ground aluminum powder (mixture No 3).

The excessive fineness of aluminum, however, adversely affects the ease of detonation. Such an effect has been observed by Apin (8) in many of the Dynammons, and has been named "hyperpulverization" by him. In Apin's opinion, a large quantity of minute particles of the combustible substance almost completely envelops the nitrate and retards its decomposition, without which the detonation cannot proceed. Analogous considerations have been put forth by Kast (3), in his investigation of aluminum explosives. The phenomenon of hyperpulverization in the ammonals has been experimentally observed in a series of projects carried out at the Institute of Physical Chemistry (1943-1945). For example, it has been established for the simplest ammonals containing large amounts of aluminum (e.g., 60/40), in which all of the aluminum is in the form of a very fine powder, that they detonate in a worse manner than in cases where the greater part of the fine powder is replaced by a coarse aluminum powder.

Some Other Properties of Aluminum Explosives

Let us examine briefly some of the other properties of aluminum explosives.

The hygroscopic and caking properties of this group of explosive mixtures are determined by the corresponding characteristics of their components. In particular, the ammonals differ little in these qualitative indices from the other ammonium nitrate explosives, which constitute one of their major drawbacks.

In the employment of the substances of this group in cake form, it is necessary to keep in mind the ability of ammonium nitrate to pass into a crystalline state with a differing specific weight at 32°.

With regard to the chemical stability of the aluminum explosives, it is the prevalent view that the aluminum contained in them tends to oxidize gradually (this is especially true for the ammonals). This must lower the ease of detonation, in contrast with the usual instances of chemical instability, which are connected with the decomposition of nitro compounds and increase the possibility of premature explosion.

The ignition temperatures for the ammonals and amatols are close to one another (220° for the first case, 210° for the second).

Percussive (and frictional) sensitivities of aluminum explosives have not been precisely determined due to the lack of reliable testing techniques. The ordinary test of Kast carried out on copra yields a distribution of values ranging over a power of 10. The introduction of a method for obtaining the relative percussive sensitivity by alternating the test explosive with a standard, has yielded uniform results which show the relatively high sensitivity of the aluminum explosives.

The strong influence of moisture on the detonative stability of 80/20 ammonal (Table 5) for example, seems to be a consequence not only of the large hygroscopic tendency of ammonium nitrate. It must be supposed that the ease of detonation

TABLE 5. The influence of moisture on the brisance of 80/20 ammonal

Moisture, %	Density, in gm/cm^3	Brisance, in mm.	
		50 gm	250 gm
0.2	1.3	21.4	22.0
0.2	1.4	21.0	18.8
0.5	1.3	21.8	21.1
0.5	1.4	22.8	17.6
1.0	1.3	20.8	3.8
1.0	1.4	19.7	0.2

of an ammonal may turn out to be worse than that of compositionally analogous Dynammons (including peat, coal, and other porous substances), with the same moisture content. This phenomenon arises from the fact that all other conditions being similar, the moisture absorbed by the Dynammon is divided between the ammonium nitrate and the combustible material, the greater porosity of the latter aiding in lowering the moisture content of the nitrate [see note]. As long as the detonative process of the ammonium nitrate explosives which do not contain explosive ingredients apparently begins with the decomposition of the nitrate, such a distribution of the moisture can have considerable significance. (Note: Analogous considerations and other facts may be found in the domestic Soviet lieterature).

That is why the ammonals without any explosive ingredients (trinitrotoluene, xylyl) whatever cannot be recommended. From this standpoint the series of ammonals established by GOST (see Table 3) is to be favorably regarded. However, the indicated quantities of aluminum and trinitrotoluene (xylyl) could be transposed without an observable loss in the moisture resistance, but with an advantageous increase in the fugacity.

In conclusion, let us mention a few interesting facts in the field of investigation concerned with the explosive mixtures of aluminum with inert materials. A. A. Shidlovskiy (Moscow Institute of Chemical Technology) has demonstrated the detonative capability of a mixture of aluminum with water. The explosive effect is weak, but readily apparent. A very strong sonic effect (but low brisance) was registered by R.Kh. Kurbangalina and Y.B. Khariton (Institute of Physical Chemistry) in the detonation of the peculiar mixture of liquid oxygen with powdered aluminum.

Conclusions

1. Aluminum has been widely used in explosive mixtures for a long time because of its high combustion energy. However, reference data on the influence of aluminum on various explosives are highly contradictory.

2. Until recently, it was generally accepted that aluminum oxide forms only after the passing of the detonation wave, and then only in the solid state. The hypothesis regarding the oxidation of aluminum in the wave front, the evaporation of the aluminum oxide in the explosion of powerful mixtures, and the consequent release of its energy of sublimation has permitted the devising of a number of experiments and the analysis of the existing contradictions.

3. It may be considered proven at the present time, that the admixture of aluminum greatly increases fugacity; increases brisance to a lesser extent (this effect is especially weak for the powerful compounds); and affects the ease of detonation less than an equal amount of an explosive additive of the trinitrotoluene type for equal degrees of fineness.

4. The considerations and conclusions stated are generally applicable to any explosive mixtures containing aluminum or other metals analogous to aluminum with respect to energy, for example, magnesium, ferrosilicon, and others.

REFERENCES

1. S. B. Ratner and Y.B. Khariton, Zhurnal fizicheskoi khimii (Journal of physical chemistry), 1946, No. 2, pp 221-22.
2. H. Muraour, Chem. Abstr. 1944, P 4446.
3. G. Kast, Vzryvchatyye veshchestva i sredstva vosplameneniya, (Explosives and means of ignition), Goskhimizdat (Gosudarstvennoye khimicheskoye izdatel'stvo -- State Chemical Publishing House), Moscow-Leningrad, 1932.
4. A. F. Belyayev, Doklady Akademii Nauk SSSR (Reports of the Academy of Sciences of the USSR), Vol. 45, No. 4, 1944, pp 164-66.
5. L. Venen, Ye. Byurlo and A. Lekorshe, Porokha i vzryvchatyye veshchestva (Gunpowders and explosives) Khimizdat (Khimicheskoye izdatel'stvo Chemical Publishing House), Moscow-Leningrad, 1936.
6. A. Stettbacher, Chemical Abstracts, 1944, p 446.
7. M. Sukharevskii, Vzryvchatyye veshchestva i vzryvnyye raboty (Explosives and Working with Explosives), Moscow, 1923.
8. A. Apin, In the compendium on the theory of explosives, Vol I, to be published by the Academy of Sciences of the USSR, (in print).
9. N. Krasel'shchik, N.Ye, Yaremenko, G. A. Shetler, Dinammony (The Dynammons), Stroyizdat Narkomstroya (Stroitel'skoye izdatel' stvo Narodnogo kommisariata stroitel'stva -- Construction Publishing House of the Peoples' Commisariat of Construction), 1943.

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